



**UNITED STATES ARMY
ENVIRONMENTAL HYGIENE
AGENCY**

ABERDEEN PROVING GROUND, MD 21010-5422

ELECTRICAL HAZARDS OF LASERS

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NA	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ELECTRICAL HAZARDS OF LASERS		5. TYPE OF REPORT & PERIOD COVERED Reprint from Electro-Optical Systems Design
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James K. Franks David H. Sliney		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS USA Environmental Hygiene Agency Aberdeen Proving Ground, MD 21010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE Dec 75
		13. NUMBER OF PAGES 5
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) lasers electrical hazards		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The eye and skin hazards associated with the use of lasers have received much attention in recent years. However, optical hazards in general are not lethal hazards, while electrocution is possible under certain circumstances. A few simple precautions can materially reduce risks.		

ELECTRICAL HAZARDS OF LASERS

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The eye and skin hazards associated with the use of lasers have received much attention in recent years. However, optical hazards in general are not lethal hazards, while electrocution is possible under certain circumstances. A few simple precautions can materially reduce risks.

Most veterans of laser research laboratories can recall at least one story of severe shock to a research worker from a high energy electrical power supply. Indeed, an early survey of accidents associated with lasers revealed that electrical accidents occurred more frequently than eye or skin injuries from laser radiation. Largely as a result of a nearly severe electrical accident at an Army laboratory, the authors conducted an in-depth study of electrical hazards associated with laser equipment. Numerous high power laser devices were evaluated to determine whether the hazardous conditions that caused this one accident were common to similar equipment. Concurrently, a general review of the physiological effects of electrical shocks was conducted. A synopsis of that study is presented here.

A Nearly Severe Accident

Not long ago, a 25 kilojoule pulsed ruby laser power supply at a government research laboratory failed to discharge its capacitors when the power supply cabinet access panel was opened. The operator tried to discharge the capacitors by means of an auxiliary grounding rod. As a final safety check prior to touching capacitor terminals, he placed a portable voltmeter across the capacitors to assure that they were discharged. The voltmeter, set on the 300 V range, was "pegged."

The laser power supply employed two output terminals, a

3 kJ output to the oscillator stage flash lamps and a 25 kJ output to the amplifier stage flash lamps of the laser. The hazardous situation occurred when a faulty resistor (open circuit) in the charging circuit permitted a 10 kV capacitor to partially charge by arcing (see Fig. 1). The capacitor would not completely discharge, because of the open circuit, even when a dump switch was activated. An estimated 2 kV potential remained across the output terminals of the laser oscillator. Since no built-in metering was employed for this output (a meter monitored the voltage across the laser amplifier stage), there was no way of knowing that the capacitor was charged.

A grounding rod was supplied with the unit, but this too had become defective. It had been dropped, causing a discontinuity (crack) in the rod. Despite the 2 kV potential existing across the capacitor, all reasonable precautions suggested that there was no charge on the capacitor. This high voltage hazard was discovered by a cautious worker when he placed the portable voltmeter across the capacitor terminals. Fortunately, no injury occurred in this instance.

Other Accidents Reported

Severe Shocks. In another government laboratory, an individual working on a laser system high voltage power supply accidentally placed his hands across a 30 kV terminal. Although he was thrown across the room and received skin burns at the points

of contact to the high voltage terminals, he did not suffer more than temporary disability.

In another case, a researcher was working with a Pockels cell electro-optic device raised to a 32 kV potential. After turning off the power supply, and since there was a small capacitor in the circuit, he touched the terminal gingerly with a shielded cable. A white spark traveled along the surface of the (apparently rather dirty) cable to his hand and then traveled along his sleeve to his elbow to a metal cabinet. He jumped or was thrown across the room. He had no burns or scars from the incident but did have a sore arm for several days. A loud "crack" accompanied the discharge.

These cases are not unique. A technician at another government laboratory was momentarily shocked (5 kV, 0.07 A from the arm to the hip). These accidents and reports of many similar nonfatal shocks from high voltage discharges led us to make this survey.

Electrocutions. At least four individuals have been electrocuted in the United States while working with laser power supplies. An experienced technician, John L. Griffen (Spacerays, Inc., Burlington, MA), lost his life as a result of forgetting to reconnect a high voltage transformer lead. He had previously cut it to reach Klystron-tube circuit components and then reached into the power supply when the power was on, apparently to troubleshoot.*

Shri K. Singh, age 20, a doc-

†LIA member

toral candidate at the Massachusetts Institute of Technology (Cambridge MA), was electrocuted while working with a far infrared gas laser with an end-plate floating at 4 kV. MIT officials reported that safety covers were not in place on the power supply.**

A third laser worker, Tyrell Schein (Raytheon, Waltham, MA) died following contact with a 15 kV circuit while trying to change a regulator tube in a CO₂ laser power supply.***

An account of the death of Stanford graduate student Charles Hawley is on page 4.

Which Lasers Are Dangerous?

Military laser range finders and similar devices with output radiant energies ranging between 50-100 mJ typically have input electrical energies of 10-20 J (e.g., 1.6 kV, 10 μ F). These electrical energies represent a potential shock hazard but would not normally be considered as a lethal shock hazard. A 1 mW HeNe laser used in construction work would typically have 10 W (2.5 mA at 4 kV) of electrical input power. Although field HeNe lasers and high power infrared gas lasers are capable of producing lethal voltages, operating personnel are normally protected by safe design. Maintenance personnel, however, can be exposed to hazardous conditions in the course of their duties.

On the other hand, high energy Q-switched lasers often found in research laboratories may have electrical inputs of 1 kJ or more with associated voltages up to 100 kV. Some high powered gas lasers also require input electrical voltages of 100 kV, achieved through the use of Marx generators. Clearly, research and maintenance personnel are high risk personnel.

Regulations, Standards and Standard Operating Procedures

Although most research laboratories utilizing high power lasers have SOPs that mention the

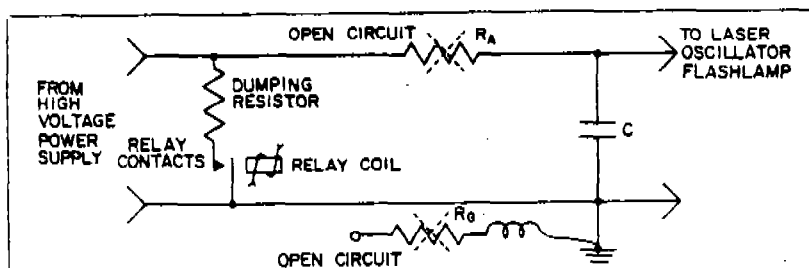


Fig. 1. R_A is open and permits capacitor C to partially charge by arcing. The capacitor is then isolated from the dumping circuit and will not discharge when the relay contacts are closed. The grounding rod R_0 is touched to the capacitor terminals, but, since it is also open, prevents C from discharging.

electrical hazards, many of these SOPs or regulations do not describe this hazard in depth. Neither do they provide detailed safety guidelines for working in the vicinity of such high voltage sources.

Among the many regulations and procedures in print, perhaps the most useful is a publication of the (then) Atomic Energy Commission entitled, "Electrical Safety Guides for Research, Safety and Fire Protection Technical Bulletin No. 13, December 1967." Besides this document, one Mil Standard (454C) provides some information on the importance of grounding electrical chassis and in dealing with safety in general, although it does not go into detail on high voltage power supplies. The American National Standards Institute (ANSI) Standard Z136.1, Safe Use of Lasers, recommends that positive protection be afforded against contact with peak open circuit potentials over 42.5 V unless the current is limited to 0.5 mA.

Physiological Effects

Most of the studies on electrical shock of value to this study were performed during the 1930s and 1940s at Columbia University and the University of California, Berkeley (many of these are cited as references in the articles listed in the accompanying selected bibliography). In these studies, it was determined that several factors establish the severity of injury associated with electric shock.

- The current path through the body
- The frequency, if alternating current

- The susceptibility of the heart in the different phases of the cardiac cycle
- Duration of the shock or discharge
- Repeated shocks in different phases of the heart cycle
- Current magnitude (not voltage)
- Skin resistance and whether the voltage is sufficient (>600 V) to break down skin resistance

A detailed discussion of the physiological effects of electric shock is beyond the scope of this presentation; however, some brief summarizing comments are in order.

It is well known that current, not voltage, determines the physiological effect of an electric shock. It is useful to distinguish quantitatively between at least four levels of effects due to continuous currents.

- A) Nonperceptible electrical currents
- B) Perceptible (perhaps painful) currents below the "let-go-threshold"
- C) Currents above the "let-go-threshold"
- D) Currents that cause ventricular fibrillation (discoordinated heart action)

For pulsed electrical discharges (as from a capacitor), the distinction between categories B and C does not exist, and the electrical energy (not current) determines the possibility of ventricular fibrillation. Several such currents and thresholds are described in Table I.

Internal body resistance is a constant value varying from 200-500 ohms, depending upon the current path; contact resistance may vary over several orders of magnitude between 1-

*Reported in *Laser Focus*, Vol. 7, No. 4, April 1971, p. 8.

**Reported in *Laser Focus*, Vol. 8, No. 10, October 1972, p. 60.

***Reported in *Laser Focus*, Vol. 10, No. 9, September 1974, p. 4.

The ventricular fibrillation threshold current is a function of current path, frequency and arrival time.

100 kilohms. High voltages may cause breakdown of contact resistance, in which case contact resistance becomes negligible.

The threshold current causing ventricular fibrillation is a function of several parameters. One such independent variable is the current path. A level of current just capable of producing fibrillation if applied between arm and chest might not cause fibrillation if applied from arm to arm across the chest. Such a level would almost certainly not produce fibrillation if applied leg to leg. Considering the body to be a distributed conductor provides an intuitive model of why this is so.

The frequency of the applied current also has an effect on the fibrillation threshold. For example, threshold currents at 25 Hz are 25% higher than at 60 Hz for shock durations of one second or more. For long durations, the thresholds approach a single value.

Finally, the arrival time of a short shock has an effect on fibrillation threshold. The heart is most susceptible during the partial refractory phase of its cycle (about 20% of the total cycle). This portion of the heart cycle is simultaneous with the T wave of the electrocardiogram. For shocks of less than 0.1 second, it is practically impossible to produce ventricular fibrillation unless such shocks coincide, at least in part, with the sensitive phase of the heart cycle.

Based upon (a more thorough) knowledge of the physiological effects of electric shock, it seems that many of the instances of nonfatal electric shock in laser laboratories were not lethal because of insufficient currents, insufficient duration of pulsed discharges or pulsed discharges occurring during non-critical periods of the cardiac cycle. Conversely, the three widely reported electrocutions

occurred when the victims completed nonpulse-type circuits.

First Aid for Severe Shock Victims

Not all laboratory and maintenance personnel were clearly familiar with first aid procedures for victims of severe shock. Some electrocution victims could have been saved if associates had realized the value of administering first aid procedures (see inset) even after cessation of heartbeat. The importance of continuing cardiopulmonary resuscitation in apparently dead victims of electric shock cannot be overemphasized. Cases have been recorded where complete recovery has been achieved even after many minutes of stopped or fibrillating heart action and cessation of respiration.

General Safety Guidelines

- Avoid wearing rings, metallic watchbands and other metallic apparel when working with electrical equipment or in the vicinity of strong induced fields.
- Whenever possible, use only one hand in working on circuits or control devices.
- Never handle electrical equipment when hands, feet or body are wet or perspiring or when standing on a wet floor.
- With high voltages, regard all floors as conductive and grounded, unless covered with suitable, well-maintained dry rubber matting.
- Learn the rescue procedures for helping the victims of apparent electrocution enumerated below.

1. Kill the circuit.
2. Remove the victim with a nonconductor if he is still in contact with an energized circuit.
3. Initiate mouth-to-mouth respiration immediately and continue until relieved by a physician (see inset).
4. Have someone call for emergency aid.

Our Recommendations

- Consider live parts of circuits and components with peak open circuit potentials over 42.5 V as hazardous, unless limited to less than 0.5 mA. Such cir-

Table I. Quantitative Effects of Electric Current on Man†

Physiologic Effect	Milliamperes					
	Direct Current		Alternating Current			
			60-Hz		10,000 Hz	
Slight sensation on hand						
Perception threshold, median						
Shock—not painful and muscular control not lost	Men	Women	Men	Women	Men	Women
Painful shock—muscular control lost by ½ %	1	0.6	0.4	0.3	7	5
Painful shock—let-go threshold, median	5.2	3.5	1.1	0.7	12	8
Painful and severe shock—breathing difficult, muscular control lost by 99½ %	9	6	1.8	1.2	17	11
Possible ventricular fibrillation	62	41	9	6	55	37
Three-second shocks	76	51	16	10.5	75	50
Short shocks (T in seconds)	90	60	23	15	94	63
Capacitor discharges	500	500	≈100	≈100		
			116/√T	116/√T		
	50*	50*				

*Energy in Joules

†Adapted from Dalziel, item 2 in bibliography

cuts require positive protection against contact.

- Install interlock switches (and capacitor bleeder resistors if applicable), or their equivalent for equipment intended for general use, to remove the voltage from accessible live parts to permit servicing operation. Bleeder resistors should be of such size and rating to carry the capacitor discharge current without burnout or mechanical damage.

- Cover or enclose circuits and components with peak open circuit potentials of 2.5 kV or more, if an appreciable capacitance is associated with the circuits.

- Use a solid metal grounding rod to assure discharge of high voltage capacitors if servicing of equipment requires entrance into an interlocked enclosure. The grounding rod should be firmly attached to ground prior to contact with the potentially live point. A resistor grounding rod (e.g., a large wattage ceramic resistor) may be used prior to application of the aforementioned solid conductor grounding rod to protect circuit components from overly rapid discharge, but not as a replacement for the solid conductor rod.

- Ground the frames, enclosures and other accessible metal noncurrent-carrying metallic parts of laser equipment. Grounding should be accomplished by providing a reliable, continuous, metallic connection between the parts to be grounded and the grounding conductor of the power wiring system.

- Provide information on elec-

trical hazard prevention to all field maintenance personnel working with lasers and all laser laboratory personnel.

- Encourage the use of shock-prevention shields, power supply enclosures and shielded leads in laboratory experimental arrangements, despite the temporary nature of some high voltage circuits.

- Supply safety devices such as safety glasses, rubber gloves and

insulating mats.

- Provide metering, control and auxiliary circuits that are suitably protected from possible high potentials, even during fault conditions.

- Perform routine inspection for deformed or leaky capacitor containers.

- Where feasible, wait 24 hours before attempting any work on circuits involving high energy capacitors.

GRAD STUDENT ELECTROCUTED

● Dies in Laser Experiment

Stanford, CA—A third-year graduate student became the most recent person to be electrocuted while working on a high-power laser experiment. Charles Hawley, 27, apparently touched a capacitor of unknown size, partially charged to about 5,000 volts. Because of the nature of the experiment, the capacitor was unshielded. Although details are sketchy as we go to press, university officials speculate that Hawley was overtired (the accident took place after midnight) and forgot that the capacitor was charged. Investigation is continuing. Three other people have died while working with high-power lasers (see "Electrical Hazards of Lasers," page 20). □

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First Aid for Shock Victims

If a person has stopped breathing or his heart has stopped beating, heart-lung resuscitation should be started at once. If the person is not breathing, do the following:

1. **Clear the throat.** Wipe out any foreign matter in his mouth with your fingers or cloth wrapped around your fingers.
 2. **Place victim on his back.** Place on a firm surface such as the floor or ground, NOT on a bed or sofa.
 3. **Tilt his head straight back.** Extend the neck up as far as possible (this will automatically keep the tongue out of the airway).
 4. **Open your mouth wide and place it tightly over the victim's mouth.** At the same time pinch the victim's nostrils shut or close the nostrils with your cheek. Or close the victim's mouth and place your mouth over his nose. This latter method is preferable with babies and small children. **BLOW** into the victim's mouth or nose with a smooth steady action until the victim's chest is seen to rise.
 5. **Remove mouth.** Listen for the return of air that indicates air exchange.
 6. **Repeat.** Continue with relatively shallow breaths, appropriate for victim's size, at the rate of one breath each five seconds.
- NOTE:** If you are not getting air exchange, quickly recheck position of head, turn victim on his side and give several sharp blows between the shoulder blades to jar foreign matter free. Sweep fingers through mouth to remove foreign matter.

After four or five breaths, stop and determine if heart is beating by checking the pulse. If the heart is beating, return to the mouth-to-mouth resuscitation and continue until breathing starts or until a physician tells you to stop.

If the heart has stopped, begin heart massage:*

1. **Place the heel of one hand on the lower third of the breastbone, the other hand on top of the first.**
2. **Thrust downward from your shoulders with enough force to depress the breastbone about 1½ to 2 inches.**
3. **Relax at the end of each stroke to permit natural expansion of the chest.**
4. **Repeat at the rate of about one per second.**

If you are alone with the victim, you must alternate mouth-to-mouth breathing with heart massage at the ratio of about 2 to 15 (two breaths, then 15 heart compressions).

If you have help, the ratio is 1 to 5. After five heart compressions, pause slightly to allow your partner to breathe once into the lungs of the victim.

CALL FOR HELP. Continue one or both of the above while the victim is being transported to the hospital, or until he revives or until told to stop by a physician.

*Adapted from item 7 in bibliography and the Los Alamos Scientific Laboratory safety manual.